International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 10, Issue 2, Apr 2020, 421–430

Original Article

MICRO-STRUCTURAL EVOLUTION ANALYSIS AND ASSESSMENT OF TRIBOLOGICAL BEHAVIOUR OF NICKEL ALLOY REINFORCED WITH SiO_2 AND Al_2O_3 HYBRID METAL MATRIX COMPOSITES

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ABSTRACT

Hybrid Metal Matrix Composites (HMMCs) enhances the main properties like wear resistance and good microstructure, as well as it saves weight. Reinforced hybrid metal matrix composites attract because it enhances wear resistance properties. Many researches are going on in material science field to strengthen the wear resistance properties of the materials and improve the quality of the material. The present research work carried out to fabricate the SiO_2 and Al_2O_3 reinforced Nickel based alloy. Reinforcement is added in matrix with 9% in weight SiO_2 (Constant) and range 3% to 12% in weight Al_2O_3 in steps of 3% in weight. Induction furnace is used to melt the composites; the composites are machined and tested after casting. Evaluation of microstructure, wear resistance of hybrid metal matrix (Monel M-35-1+SiO_2+ Al_2O_3) is done and analyzed. From results, it is clear that the SiO2 and Al_2O_3 added with Nickel alloy shows good microstructure and reduced wear properties of composites.

KEYWORDS: Nickel Alloy; SiO_2; Al_2O_3; & Stir Casting

Received: Jan 21, 2020; **Accepted:** Feb 11, 2020; **Published:** Mar 10, 2020; **Paper Id.:** IJMPERDAPR202038

INTRODUCTION

In today's word, the composite material has progressive increase in growth with greater strength and less weight, higher stiffness and thermal stability. With the combination of two or more materials, we can achieve considerable variation in the chemical and physical properties, which make a dissimilar in the kind material compare to original individual materials such built materials are named as composite materials. Two constituents, which are present in a composite material, are base metal (matrix) and reinforcement with their presence gives greater properties compared to that of individual element property.

The matrix material generally made of base metal, fasten the reinforcement, due to this the physical shape and dimensions of the composite materials get good control in the process of manufacturing. It also protects the reinforcement from ecological effects and transmits the load applied on the composite to the reinforcement, which is mainly the load taking part. Necessary stiffness, strength and thermal stability of the composites are expanded due to its reinforcement within the composite. To achieve combinations of properties not attainable with metals, ceramics, or polymers alone using combination of two materials in composites. In Automotive industry, Railways,

Aircrafts, Marine application HMMCs are used.

Due to rapid development in industrial application like marine, aerospace and automobile etc, lots of researches are going on in the field of material science engineering. Various research has been done using various combinations of materials with different reinforcement of varying size, shape and different weight percentage of numerous composite materials are fabricated. The allotment of matrix alloy should be uniform to gain the ultimate properties of the metal matrix composite (MMC) [1].

Metallurgists need to adopt recent technologies to build up a novel metal for latest industrial applications using traditional manufacturing methods. Through this it is achievable for metallurgist to find the solution to improve the properties like mechanical, thermal and wear resistance of the materials. Therefore, an investigation in the present research was made to fabricate and evaluate the microstructure and wear behavior of composites developed using stir casting route with nickel alloy matrix and silicon dioxide and aluminum oxide as the reinforcement. With other metals and materials nickel made significant contributions in elemental or alloyed form in the society at present-days and even it will continue to provide resources for future depends on demand. A versatile element nickel will alloy with most metals. It has capacity to endure a wide range of severe working circumstances involving corrosive nature, elevated temperatures, stresses, strength, toughness at higher rate, stability to metallurgical phenomenon, fabrication process and due to all these reasons nickel and nickel alloys are used for an extensive range of purposes [2-6]. Particle substantiate nickel MMCs are now a days reconstruct by the traditional materials in various domain of engineering because of its high soundness and better wear resistance properties [7].

The best part of which inhabit resistance to the corrosion and/or resistance to the heat, gas turbines used in the aircraft, power plants steam turbine, and nuclear power systems, industries like chemical and petrochemical. The requirement for such efficient material to offer high concert has effected in constant attempts being made mainly in alloy design areas and the processing techniques have novelty to build up composites material as severe challengers to the conventional manufacturing alloys [8-13].

Nickel alloys belong to super alloy category due to its good mechanical and thermal properties. Nickel alloy exhibits wear and corrosion resistance. In this research work, Monel is used. Monel belongs to one of the nickel alloy group; it primarily composed of nickel and copper. We are fabricated hybrid metal composites using Monel as base metal with Silicon Dioxide (SiO_2) and Aluminium Oxide (Al_2O_3) are the reinforcements.

Silicon Dioxide (SiO_2) is also called as silica. Silica is commonly available in the form of quartz, used for manufacturing ceramics. In the present SiO_2 there are major constituents for making composite materials due to its several industrial applications.

Aluminium oxide (Al_2O_3) has aluminium and oxygen chemical compounds. Alumina gives high refractoriness with low cost. Aluminium oxide is good electric insulator as well as provides good thermal conductivity and also gives good hardness. It used in valve seats, seal faces, electrical insulators and fibre reinforcement in composite material etc. There are several series of nickel alloys are available and ASTM A 494 M Grade Nickel Alloy is one in between them, which is a favourite option for producing MMCs due to good mechanical and wear behaviour [14,15].

ASTM A 494 M Grade Nickel Alloy includes SiO_2 and Al_2O_3 provides best properties like strength, hardness and tribological properties of composites [16]. Stir casting is one of the popular techniques which are used in many applications

[17, 18]. SiO_2 is better adding material due its mechanical [19–21] and wear resistant property [22].

A limited study was done on SiO_2 and Al_2O_3 with nickel alloy. So, the existing analysis done with SiO_2 and Al_2O_3 as a substitute material to nickel alloy casting using stir casting method. In the existing work, study is conducted to exploit a hybrid MMC with SiO_2 and Al_2O_3 constitution and evaluated for microstructure and wear resistance.Reinforcement is added in matrix with 9% in weight SiO_2 (Constant) and varying 3% to 12% in weight Al_2O_3 in steps of 3% in weight and its microstructure and wear resistance were measured.

This research paper content is organized as follows. Materials used and methodology section gives the brief idea about which materials are used for this experiment and chemical composition of material as well as methodology used for conduction of the experiment. In section Composite testing, we discussed about how we tested material. The proposed work and the corresponding results are discussed in section in results and discussion section. Research work is concluded in conclusion section.

MATERIALS USED AND METHODOLOGY

Reinforcement is added in Nickel alloy matrix with 9% in weight SiO_2 (Constant) and varying 3% to 12% in weight Al_2O_3 in steps of 3% in weight was made using of stir casting method. The specimens made from the ready composite using CNC machine to conduct various tests. The ready specimens were tested for microstructure analysis to find dispersion of added particles in matrix alloy. The obtained outcome was matched with the nickel alloy to verify the exercise. Here, nickel alloy was taken as a base material (Monel), and its chemical content is displayed in table 1. SiO_2 particles and Al_2O_3 particulates were used as reinforcement.

The 9 wt% of SiO_2 composition was kept equal all over the exercise while Al_2O_3 differs from 3 wt. % to 12 wt. % with an increment of 3 wt. %. Initially, a measured amount of nickel alloy plates was put into the crucible and superheated to its melting temperature of about 1600°C in an induction furnace. A stirring action was carried out to accomplish static dispersion of added materials by using a stirrer mechanically [10]. Reinforcing material Al_2O_3 is preheated to 800^0C and SiO_2 preheated to 500^0C in a different furnace to raise the wet ability.

Table 1: Chemical Composition of Monel M-35-1

	Ni		**C**	**P**	**Si**	**Cu**	**Fe**	**Mn**
Composition in weight %	Balance		0.916	0.0232	0.8	26.6	0.513	3.02
Element	**S**		**Al**	**Pb**	**Sn**	**Cr**	**Co**	**Ti**
Composition in weight %	0.0027		0.112	0.0753	0.0237	0.0252	0.0826	0.121

Composites of variant constitution taken in research work:

Sample 1 Monel M-35-1

Sample 2 Monel M-35-1 + 9 wt% SiO_2+3 wt% Al_2O_3

Sample 3 Monel -M-35-1+ 9 wt% SiO_2+6 wt% Al_2O_3

Sample 4 Monel -M-35-1+ 9 wt% SiO_2+9 wt% Al_2O_3

Sample 5 Monel-M-35-1 + 9 wt% SiO_2+12 wt% Al_2O_3

Handling the heterogeneous particle distribution is biggest problems in the process casting particularly in metal matrix composites. The composites are fabricated using Stir casting method, which involves stirring of molten metal continuously. The molten metal surface is exposed to the atmosphere which forms oxidation of melted material. Due this process, continuous oxidation takes place which results good wet ability for the molten metal.

The already heated blend of SiO_2 and Al_2O_3 was dropped into a furnace consisting of melted Monel M-35-1. While adding, the reinforcement uniformity is maintained. The stirring exercise has been carried out using mechanical stirrer at a speed of 500 rpm. Once molten metal of composites is ready, poured into the mould of size 225mm*50mm*25mm already prepared by the help of silica sand containing 5% moisture, also using 5% bentonite as binding material and lastly dried out. Removing the internal gases present in the mould area by passing nitrogen gas, meanwhile it is weighty, settle down inside the mould cavity and pushes out other gases present in the mould.

Solidification takes place in open air once the molten metal poured into the cavity which is already made. The process of production was recast for other weight percentage of Al_2O_3 (3, 6, 9 and 12wt %) with constant 9wt% of SiO_2 in the HMMCs. In table 2 shows the other combinations of composites.

Figure 1(a) shows sand mould prepared for preparing the composites and figure1 (b) shows molten metal ready with base mixture of base metal Monel and reinforcements.

(a) (b)

Figure 1: (a) Sand Mould (b) Induction Furnace with Molten Metal.

COMPOSITES TESTING

The machining of developed material was carried out to make the samples to find the micro structural and wear behaviour for base metal and other combinations. The small-scale structure of the material is called microstructure. The surfaces have relative motion with each other contacting wear occurs, due to this material loss takes place progressively. This research paper shows detailed study of microstructure and wear resistant of the developed hybrid metal matrix composites.

Figure 2: Metallurgical Microscope.

Microstructure study was performed, using microscope, as shown in figure 2, specimens were observed to study the microstructure of the castings from selected area. Microstructural investigation was done using NIKON, ECLIPSE LV 150 optical metallurgical microscope. Microscopically investigation has been done for the specimens prepared as per ASTM standards.

For conducting wear study computerised pin on disc apparatus used as shown in figure 3. For 20N, 40N, 60N loads and speeds 200 rpm, 300 rpm and 400 rpm with 1000 m sliding distance maintained same for all the tests using a specimen of dimension as per ASTM G99- 05 standard with the help of rotating steel disc wear rate is measured. Figure 4 shows the specimens used for test.

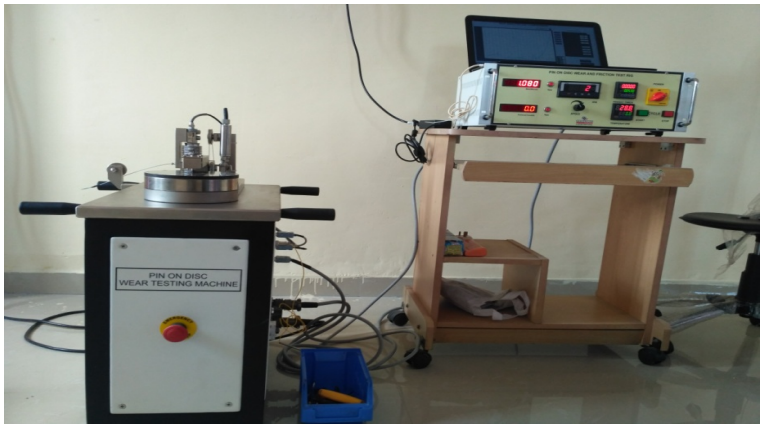

Figure 3: Wear Test Machine.

Figure 4: Specimens used for Wear Test.

RESULTS AND DISCUSSIONS

Microstructure Study

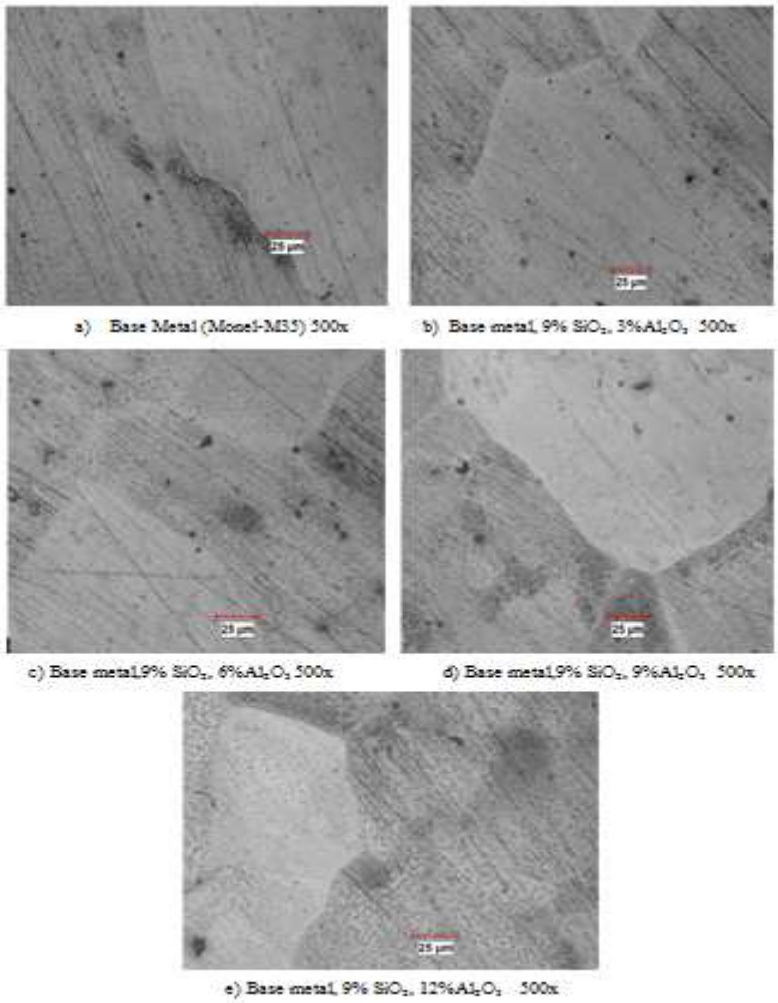

Figure 5: Microstructures of Base Metal, Constant wt% of SiO_2 and Different wt % of Al_2O_3.

In the present work, Monel-M-35-1 reinforced with constant wt% of $SiO_2$and varying wt % of Al_2O_3 particles were used in the MMCs. Figure 5 shows the microphotographs of Monel -M-35-1, Monel-M-35-1+9wt% SiO_2(constant) with 3,6,9 and 12 wt.% Al_2O_3 individually. Figure 5(a-e) disclose correct dispersion of SiO_2 and Al_2O_3 particulates in Nickel alloy. The dispersion of particles may be achieved due to swirling action through stir casting.

Microstructure is free from micro porosities that have been observed in the pictures. From micro structural revisions, the adherence is absolute within the matrix and reinforcement due to heat beforehand of reinforcement and no dissimilarity within them is noticed.

Wear Performance

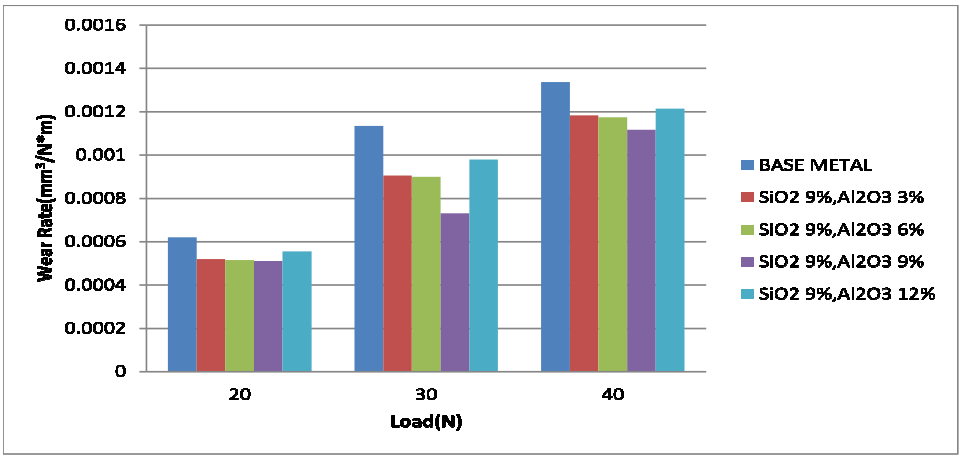

Figure 6: Impact of Load on Wear Rate.

With distinct load condition and different sliding speeds rate of wear in the samples were determined taking persistent sliding distance of 1000m at ambient temperature. Figure 6 shows for 20N, 30N and 40N loads the variation of wear rate of composites. The wear loss of Monel M-35-1 is high corresponding to reinforced materials can be seen.

Due to the addition of SiO_2 and Al_2O_3 particulates the decreased rate of wear is achieved. Further, it shows the wear rate is correlative with load, as rise in load tends to higher the rate of wear. An average of rate of wear increased up to double with load of 40N from 20N is noticed. So, we can observe against the load wear rate will be vary uniformly.

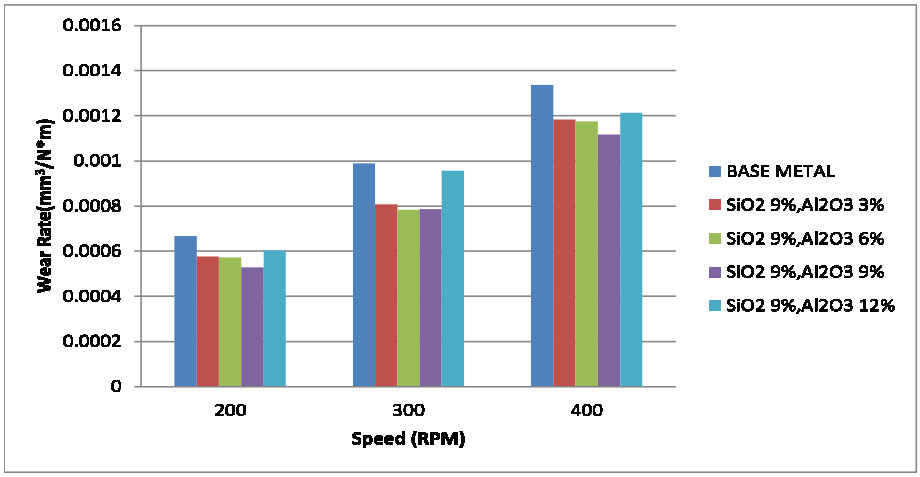

Figure 7: Sliding Speed Effect on Wear Rate.

For different sliding speeds of 200 rpm, 300 rpm and 400 rpm at 40N load with fixed 1000 m sliding distance, composites wear rate has been calculated. Figure 7 shows that with the addition of SiO_2 and Al_2O_3 particles were increased composites wear resistance. Rate of wear is high without reinforced alloy compared to composites with reinforcement.

From the figure 7, the wear rate is increased for greater sliding speed has been observed. At the rate of an average double increasing wear rate noticed from sliding speed of 200 rpm to 400 rpm. Higher the sliding speed, friction between rubbing surfaces are more as a result despoil of the material quickly due to heat developed on the surface.

CONCLUSIONS

- Using stir casting method, we can cast Nickel based alloy hybrid metal matrix composite successfully using electric induction furnace for melting.
- Microstructure of the hybrid composites (Monel M-35-1+SiO_2+Al_2O_3) is better compared to metal matrix alloy with dispersion of only fused SiO_2. Coherence bond was strong and it is observed with no agglomeration between the dispersoid and the matrix.
- Composites were fabricated by substitution of fixed amount of (9 wt %) $SiO_2$and different wt% of Al_2O_3 to the Nickel alloy. Reinforcement particles distributed uniformly in Monel M-35-1 (base metal) proved from the microstructure analysis.
- To know the tribological behaviour of Monel-M-35-1 added with SiO_2 and Al_2O_3 particulates fabricated, an attempt is made with the use of stir casting approach.
- The increase of wear resistance is observed in case of Monel-M-35-1 (Base metal) with the addition of 9 wt% SiO_2 and 9 wt% Al_2O_3 particulates as compared to nickel alloy with 9 wt% SiO_2(constant) and other wt% of Al_2O_3 (3,6 and 12) of composites.

REFERENCES

1. *Hashim, J., Looney, L. and Hashmi, M.S.J., 1999. Metal matrix composites: production by the stir casting method. Journal of materials processing technology, 92, pp.1-7.*
2. *Theriault A, Xue L, Dryden JR., 2009. Fatigue behavior of laser consolidated IN-625 at room and elevated temperatures. Materials Science and Engineering: A. 516(1-2), p.p. 217-25.*
3. *Shankar, Vani, K. Bhanu Sankara Rao, and S. L. Mannan., 2001, "Microstructure and mechanical properties of Inconel 625 superalloy." Journal of nuclear materials 288.2-3, p.p. 222-232.*
4. *Thivillon L, Bertrand P, Laget B, Smurov I., 2009, Potential of direct metal deposition technology for manufacturing thick functionally graded coatings and parts for reactors components. Journal of Nuclear Materials. 385(2), p.p.236-41.*
5. *Ganesh P, Kaul R, Paul CP, Tiwari P, Rai SK, Prasad RC, Kukreja LM., 2010,. Fatigue and fracture toughness characteristics of laser rapid manufactured Inconel 625 structures. Materials Science and Engineering: A. 527(29-30), p.p .7490-7.*
6. *Song KH, Nakata K., 2010, Effect of precipitation on post-heat-treated Inconel 625 alloy after friction stir welding. Materials & Design., p.p. 2942-7.*
7. *Shetty, Vidyasagar, and Vijaya kumar. "an Effect of Sio2 and Carbon Nano Tubes on Mechanical Properties of lm-12 Aluminium Alloy Hybrid Metal Matrix Composite."*
8. *Chawla, Nikhilesh, and Y.L. Shen., 2001, "Mechanical behavior of particle reinforced metal matrix composites." Advanced engineering materials, .03(06), p.p 357-370.*
9. *Yang X, Ren Z, Meng, Shehzad K and Qu S., 2015, Mechanical properties of nickel – grapheme composites synthesized by electrochemical deposition, Nanotechnology, 26 (6), pp. 5706.*
10. *Purshotham G and Hemanth J,2014, Action of chills on microstructure, mechanical properties of chilled ASTM A494 M grade Nickel alloy reinforced with fused SiO2 MMC, Procedia Material Science, 5, pp. 426-33.*

11. *Zhang L, Shi N, Gong J and Sun C, 2011, Preparation of SiC Fiber Reinforced Nickel Matrix Composite, Journal Material Science Technology, 28(3), pp. 234-40.*
12. *Novák P, et al., 2010, Preparation of Nickel ceramics composite by reactive sintering, Department of Metals and Corrosion Engineering, Institute of Chemical Technology, 5, pp. 166-28.*
13. *Lu J, Yang S, Wang J and Xue Q. 2001, Mechanical and tribological properties of Ni-based alloy/CeF3/graphite high temperature self-lubricating composites, Wear, 249(12), pp.1070–76.*
14. *Smith W F, Structure and properties of engineering alloys, second edition, McGraw-Hill: New York, 1993.*
15. *Reddy, Thallapaka Theja. "Corrosion and Wear Behavior of Aluminum Alloy Hybrid Metal Matrix-a Review."*
16. *Sharma, P., Paliwal, K., Garg, R.K., Sharma, S. and Khanduja, D., 2017. A study on wear behaviour of Al/6101/graphite composites. Journal of Asian Ceramic Societies, 5(1), pp.42-48.*
17. *Rao, V.R., Ramanaiah, N. and Sarcar, M.M.M., 2016. Dry sliding wear behavior of TiC-AA7075 metal matrix composites. International Journal of Applied Science and Engineering, 14(1), pp.27-37.*
18. *Purushotham, G., and Joel Hemanth. "Action of chills on microstructure, mechanical properties of chilled ASTM A 494 M grade Nickel alloy reinforced with fused SiO2 metal matrix composite." Procedia Materials Science 5 (2014): 426-433.*
19. *Swetha, D., N. Jaya Krishna, and Sm Saleemuddin. "Investigation of Mechanical & Metallurgical Properties of Hybrid Metal Matrix Composites."*
20. *Nagaral, M., Auradi, V. and Kori, S.A., 2015. Microstructure and mechanical properties of Al6061-graphite composites fabricated by stir-casting process. In Applied Mechanics and Materials (Vol. 766, pp. 308-314). Trans Tech Publications.*
21. *Mohanavel, V., Rajan, K. and Ravichandran, M., 2016. Synthesis, characterization and properties of stir cast AA6351-aluminium nitride (AlN) composites. Journal of Materials Research, 31(24), pp.3824-3831.*
22. *Joel Hemanth, Cryo effect during solidification on the tribological of Aluminium- alloy/glass (SiO2) MMC. Journal of composite materials, vol.43, No.06 (2009).*
23. *Umanath, K.P.S.S.K., Palanikumar, K. and Selvamani, S.T., 2013. Analysis of dry sliding wear behaviour of Al6061/SiC/Al2O3 hybrid metal matrix composites. Composites Part B: Engineering, 53, pp.159-168.*
24. *El-Shennawy, M., and Adel A. Omar. "Manufacturing of Nano/Micro Composites using Friction Stir Processing."*
25. *Manjunatha, L.H. and Dinesh, P., 2012. Development and study on microstructure, hardness and wear properties of as cast, heat treated and extruded cnt-reinforced with 6061al metal matrix composites. International Journal of Mechanical Engineering & Technology (IJMET), 3(3), pp.583-598.*
26. *C.S. Ramesh, R. NnoorAhmed, M.Z. Abdullah, 2009, Development and performance analysis of novel cast copper - SiC Gr hybrid composites, Materials and Design, PP 1957-1965.*
27. *Wei, J.N., Cheng, H.F.,Zzhang, Y.F., Han, F.S., Zhou, Z.C. and Shui, J.P., 2002. Effects of macroscopic graphite particulates on the damping behavior of commercially pure aluminum. Materials science and engineering: a, 325(1-2), pp.444-453.*
28. *S Ramesh, R. NnoorAhmed, M.Z. Abdullah, 2009, Development and performance analysis of novel cast copper - SiC Gr hybrid composites, Materials and Design, PP 1957-1965.*
29. *Wei, J.N., Cheng, H.F.,Zzhang, Y.F., Han, F.S., Zhou, Z.C. and Shui, J.P., 2002. Effects of macroscopic graphite particulates on the damping behavior of commercially pure aluminum. Materials science and engineering: a, 325(1-2), pp.444-453.*

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